ANALYSIS OF INDOT CURRENT HYDRAULIC POLICIES

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# Analysis of INDOT Current Hydraulic Policies

Hydraulic design often tends to be on a conservative side for safety reasons. Hydraulic structures are typically oversized with the goal being reduced future maintenance costs, and to reduce the risk of property owner complaints. This approach leads to a conservative design with higher construction costs. Therefore, there is a need to quantify the cost-benefit aspect of this conservative approach. Accordingly, the overall objective of this project is to compare hydraulic design policies of Indiana Department of Transportation (INDOT) with that of other states, and perform cost-benefit analysis of large versus smaller hydraulic structures in terms of capital and maintenance costs. Comparison of INDOT’s culvert design is similar to that of Michigan, and is most updated compared to Ohio, Illinois and Kentucky. INDOT uses $Q_{100}$ as the design discharge, which is conservative compared to other neighboring states that use $Q_{50}$ as the design discharge for designing culverts. By using the data from 16 culvert design examples including both new-alignment and replacement structures, cost benefit analysis is performed in the light of suggested revision in culvert hydraulics policy. Results show that an increase in backwater limit to 1’ will result in 44% reduction in culvert size (represented as culvert area) with an average backwater of 0.79’. Increase in backwater limit will also increase the outlet velocity by 72% that may result into extra cost in outlet protection structures. Depending on the type and the size of the culvert, a change in hydraulic policy may result in saving from 12 -58% of the original cost associated with the current conservative design.
EXECUTIVE SUMMARY

PROJECT MANAGEMENT TRAINING

Introduction

Hydraulic design often tends to be on a conservative side for safety reasons. Hydraulic structures are typically oversized, with the goal being reduced future maintenance costs and reduced risk of property owner complaints. This approach leads to a conservative design with higher construction costs. Therefore, there is a need to quantify the cost-benefit aspect of this conservative approach. Accordingly, this project has the following three objectives:

(i) Compare design policies of INDOT with those of border states (Ohio, Illinois, Michigan, and Kentucky); (ii) Perform cost-benefit analysis of large versus smaller hydraulic structures in terms of capital and maintenance costs; and (iii) Investigate ways to improve the hydraulic design by looking at the effect of input data and sources.

Findings

- In general, the hydrologic design policies implemented by Indiana (INDOT) and Michigan are most updated compared to Ohio, Illinois, and Kentucky design policies. For example, INDOT uses TR20 and HEC1 software programs for computing design discharge, whereas Illinois hydrologic policy recommends the use of USGS regression equations.
- The magnitude of INDOT design discharge ($Q_{100}$) is conservative in comparison to Illinois and Kentucky design discharge ($Q_{50}$ or less). The magnitude of design discharge for Michigan and Ohio is similar to that for Indiana.
- INDOT’s culvert design discharge magnitude ($Q_{100}$) is conservative in comparison to other states’ culvert design discharge magnitudes. For example, Illinois uses $Q_{50}$ as design discharge compared to $Q_{100}$ by Indiana.
- INDOT’s maximum backwater limit criterion (1.5”) for new alignment culverts is not found in neighboring states’ design manual. The maximum backwater limit criterion becomes limit criterion for culvert design (culvert size) in many cases.
- An increase in backwater limit to 1’ will result in 44% reduction in culvert size (represented as culvert area) with an average backwater of 0.79’. Increase in backwater limit will also increase the outlet velocity by 72% that may result into extra cost in outlet protection structures.
- Depending on the type and the size of the culvert, a change in hydraulic policy may result in saving from 12 to 58% of the original cost associated with the current conservative design.

Implementation

The hydraulics division at INDOT will use the findings from the final project report in determining the modifications to the current hydraulics design policies.
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**INTRODUCTION**

Hydraulics plays a major role in highway engineering to collect, transport, and dispose surface water originating on or near the highway right-of-way, to handle river and other water crossings, and to handle subsurface water conditions. Hydraulic or drainage design is a unique field of Civil Engineering, because most often it relies on empirical equations, judgment, experience, and common sense to find answers to engineering questions. The hydraulic engineering judgments or decisions are guided by drainage design methodologies. Therefore, the drainage designer must fully understand each method that is employed, including its limitations. Because of this empirical approach, hydraulic designs tend to be on a conservative side for safety reasons. Hydraulic structures are typically oversized to reduce future maintenance costs the risk of property owner complaints. This approach leads to conservative design with higher construction costs. Therefore, there is a need to quantify the cost-benefit aspect of this conservative approach. There is a need to quantify the trade-off between conservative design versus maintenance and legal costs due to complaints/lawsuits from property owners. In addition, the INDOT Production Management Division has been asked to provide suggestions for reducing construction costs. Studying culvert sizing policies to determine situations for making less conservative design would be a good starting point in reducing the overall construction costs. Accordingly, this project has the following three objectives:

1. Compare design policies of INDOT with those of border states (Ohio, Illinois, Michigan, and Kentucky).
2. Perform cost-benefit analysis of large versus smaller hydraulic structures in terms of capital and maintenance costs.
3. Investigate ways to improve the hydraulic design by looking at the effect of input data and sources.

Description of the project task related to each objective is presented in the following sections.

**TASK 1: COMPARATIVE ANALYSIS OF DESIGN POLICIES AND PROCEDURES**

### 1.1 Hydrologic Policy Comparison

This task compared INDOT hydrologic policies for culvert and bridge design (Chapters 29, 31, and 32) with design policies from neighboring states including Illinois, Michigan, Ohio, and Kentucky. A comparison of design discharge calculation methods and magnitudes are shown in Tables 1.1 and 1.2, respectively. Major findings from this task are:

1. In general, the hydrologic design policies implemented by Indiana (INDOT) and Michigan are most updated compared to Ohio, Illinois, and Kentucky design policies. For example, INDOT uses TR20 and HEC1 software programs for computing design discharge, whereas Illinois hydrologic policy recommends the use of USGS regression equations.
2. The magnitude of INDOT design discharge (Q100) is conservative in comparison to Illinois and Kentucky design discharge (Q50 or less). The magnitude of design discharge for Michigan and Ohio is similar to that for Indiana (Table 1.2).

### 1.2 Culvert Design Policy Comparison

A comparison of culvert design policy for all 5 states (IN, IL, OH, MI, and KY) is presented in Table 1.3. Major findings from this comparison are:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Facility/Structure</th>
<th>Preference 1</th>
<th>Preference 2</th>
<th>Only for Preliminary Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INDIANA</strong> (Indiana, 2011)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Stream flow, Bridges, and large Culverts</td>
<td>INDR Coordinated Curve</td>
<td>TR 20, HEC1</td>
<td>USGS Regression Equations</td>
</tr>
<tr>
<td>2</td>
<td>Small Culverts</td>
<td>TR20, HEC1</td>
<td>Rational method</td>
<td>USGS Regression Equations</td>
</tr>
<tr>
<td>3</td>
<td>Storm Drain, Roadside Culverts, Inlet Spacing</td>
<td>Rational Method (for &lt; 200 acres in rural area)</td>
<td>TR 20, HEC1</td>
<td></td>
</tr>
<tr>
<td><strong>ILLINOIS</strong> (Illinois, 2011)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Bridges, Culverts, and Channel</td>
<td>USGS Regression Equations</td>
<td>TR20, HEC1</td>
<td></td>
</tr>
<tr>
<td><strong>MICHIGAN</strong> (Michigan, 2011)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>DA &gt; 2 Sq. Miles</td>
<td>MDEQ - SCS, regression, and Runoff Models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20 Acres &lt; DA &lt; 2 Sq. Miles</td>
<td>MDEQ-SCS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>DA &lt; 20 Acres</td>
<td>Rational Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OHIO</strong> (Ohio, 2011)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>DA &gt; 6 Acres</td>
<td>USGS Regression Equations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>DA &lt; 6 Acres</td>
<td>Rational Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>KENTUCKY</strong> (Kentucky, 2011)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>DA &gt; 1000 Sq. Miles</td>
<td>USGS Regression Equations (Food in Kentucky method)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>200 Acres &lt; DA &lt; 1000 sq. miles</td>
<td>USGS Regression Equations (Regional method)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>DA &lt; 200 Acres</td>
<td>Rational Method</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Note: DA represents Drainage Area)
### TABLE 1.2
Comparison of Design Discharge

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Facility Classification</th>
<th>Bridge water way opening</th>
<th>Roadway Cross Culverts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Allowable backwater</td>
<td>Allowable velocity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Allowable backwater</td>
<td>Allowable velocity</td>
</tr>
<tr>
<td>1</td>
<td>Freeways</td>
<td>Q100</td>
<td>Q100</td>
</tr>
<tr>
<td>2</td>
<td>Multilane Non-Freeways</td>
<td>Q100</td>
<td>Q100</td>
</tr>
<tr>
<td>3</td>
<td>Two lane Facility*</td>
<td>Q100</td>
<td>Q100</td>
</tr>
<tr>
<td>3a</td>
<td>AADT ≥ 3000</td>
<td>Q100</td>
<td>Q100</td>
</tr>
<tr>
<td>3b</td>
<td>3000 &gt; AADT &gt; 1000</td>
<td>Q100</td>
<td>Q100</td>
</tr>
<tr>
<td>3c</td>
<td>AADT &lt; 1000</td>
<td>Q100</td>
<td>Q100</td>
</tr>
</tbody>
</table>

* Traffic volume are for a 20-year projection

### ILLINOIS
Sl. No. | Facility | Rural highways | Urban highways
--------|----------|----------------|------------------|
1       | Bridges and Culverts | Q50 | Q50 |

Note: TWS-2: Two way street, 2 Lane

### MICHIGAN
Sl. No. | Facility Classification | Design discharge |
--------|-------------------------|-------------------|
1       | All Highways Encroaching on the floodplain | Q100 |

### OHIO
Sl. No. | Facility Classification | Design discharge |
--------|-------------------------|-------------------|
1       | All Highways Encroaching on the floodplain | Q100 |
2       | Flood Clearance          |                   |
2a      | Freeways or other multi-lane facilities with limited or controlled access | Q50 |
2b      | Other highways (2000 ADT and over) and Freeway Ramps | Q25 |
2c      | Other highways (under 2000 ADT) | Q10 |

### KENTUCKY*
Sl. No. | Facility Classification | Traffic Volume | Design discharge |
--------|-------------------------|----------------|-------------------|
1       | Bridges ADT < 400      | Q10            | Q100 for check due to flood hazard |
1       | 400 < ADT < 1500       | Q25            | Q100 for check due to flood hazard |
1       | 1500 < ADT             | Q50            | Q100 for check due to flood hazard |
2       | Culverts ADT < 400     | Q10            | Q50 for design and Q100 for check due to flood hazard |
2       | 400 < ADT < 1500       | Q25            | Q100 for check due to flood hazard |
2       | 1500 < ADT             | Q25            | Q100 for check due to flood hazard |

* Kentucky drainage manual is being updated and the updated version is not yet available

### TABLE 1.3
Comparison of Culvert Design Policy

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Group</th>
<th>Subgroup</th>
<th>IN</th>
<th>IL</th>
<th>MI</th>
<th>OH</th>
<th>KY</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design Discharge</td>
<td></td>
<td>Q100</td>
<td>Q50</td>
<td>Q50 for design and Q100 for check</td>
<td>Q25 for design and Q100 for check due to flood hazard</td>
<td>Q25 for design and Q100 for check due to flood hazard</td>
<td>Analyze the mean life span of the culvert and find out whether Q50 or Q100 is more suitable</td>
</tr>
<tr>
<td>2</td>
<td>Maximum Backwater / Allowable Head Water (AHW)</td>
<td>1.5&quot;</td>
<td>Two feet below for Q100</td>
<td>a) pavement elevation</td>
<td>b) prevent damage to upstream properties</td>
<td>Two feet below the low edge of pavement for DA &gt; = 1000 acres and one feet for DA &lt; 1000 acres</td>
<td>a) based on sound judgment b) use Q500 for Nuclear Power Plants, Q100 for houses, and Q25 for farmland and barrens</td>
<td>1.5&quot; backwater becomes main limiting criteria for AHW</td>
</tr>
</tbody>
</table>

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Joint Transportation Research Program Technical Report FHWA/IN/JTRP-2011/08
### TABLE 1.3
Comparison of Culvert Design Policy (Cont’d)

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Group</th>
<th>Subgroup</th>
<th>IN</th>
<th>IL</th>
<th>OH</th>
<th>MI</th>
<th>KY</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Cover</td>
<td>For circular pipe</td>
<td>cover &gt; 1’</td>
<td>minimum 6” for circular pipe</td>
<td>Adequate cover</td>
<td>a) For corrugated steel and aluminum box culverts and corrugated steel long span culverts: cover &gt; 18”</td>
<td>b) For PRC Arc Section: 1’&lt;cover&lt;12’</td>
<td>a) Minimum cover : 1 ft, but 2 ft is desirable may be 100 ft is misprint, it should be 10 ft</td>
</tr>
<tr>
<td>4</td>
<td>Maximum Outlet Velocity (Vo)</td>
<td>a) Revetment riprap for Vo &lt; 6.5 ft/s</td>
<td>1) Rule of thumb: Vo &lt; 10 ft/s</td>
<td>2) should be based on amount of sediment in the flow or abrasive potential to the culvert</td>
<td>a) For Vo &lt; 6 ft/s : no special treatment</td>
<td>a) For Vo &lt; 5 ft/s: no protection</td>
<td>Not Found</td>
<td>b) Class 1 riprap for 6.5 ft/s &lt; Vo &lt; 10 ft/s</td>
</tr>
</tbody>
</table>

### TABLE 1.4
Main features of INDOT’s bridge design policy

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Group</th>
<th>Subgroup</th>
<th>IN</th>
<th>IL</th>
<th>OH</th>
<th>MI</th>
<th>KY</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design Strom Frequency</td>
<td>Allowable backwater, Roadway Serviceability, Note 1</td>
<td>Q100</td>
<td>Q100/Q25/Q10, Note 2</td>
<td>Q100</td>
<td>Q100/Q25/Q10, Note 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>design program</td>
<td>WSPRO and HEC-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Back water</td>
<td>IDNR or INDOT criteria, backwater should not exceed 1.5”, Note 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>free board</td>
<td>minimum 2-ft for passage of ice and debris</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Bridge Sizing</td>
<td>a. does not require IDNR permit</td>
<td>DA &gt; 50 mi2 in rural area and DA &gt; 1 mi2 in urban area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Span length</td>
<td>for bridge &gt; 3 spans</td>
<td>minimum span length should be &gt; 100 ft for the spans over the main channel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Scour Depth</td>
<td>for bridge foundation</td>
<td>Maximum scour depth for Q100 flood, and apply a geotechnical factor of safety 2 to 3, check with Q500 (Q100 * 1.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Temporary-Runaround structure</td>
<td>Road Serviceability</td>
<td>Q25/ Q10/ Q2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Channel Clearing</td>
<td>Allowable Velocity</td>
<td>Q10/Q10/Q2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** The traveled way overtopping flood level identifies the limit of serviceability  
**Note 2:** Q100 is for: Freeway, Multilane Non-Freeway, Two Lane facility with AADT ≥ 3000 and ramp, Q25 is for: Two lane facility with 1000 < AADT < 3000, and Q10 is for: Two lane facility with AADT < 1000, and Q10 is for: Two lane facility with AADT < 1000  
**Note 3:** Hydraulic engineer approval is required to exceed the limit of 1.5”  
**Note 4:** FHWA does not require economic justification for a bridge that causes less than 12” of backwater Therefore, a formal risk assessment will not be required
INDOT’s culvert design discharge magnitude (Q\textsubscript{100}) is conservative in comparison to other states’ culvert design discharge magnitudes. For example, Illinois uses Q\textsubscript{50} as design discharge compared to Q\textsubscript{100} by Indiana.

INDOT’s maximum back water limit criterion (1.5”) for new alignment culverts is not found in neighboring states’ design manual (Table 1.3). The maximum back water limit criterion becomes limit criterion for culvert design (culvert size) in many cases.

### 1.3 Bridge Design Policy Comparison

The main features of INDOT design policy are listed in Table 1.4. Comparison of INDOT’s bridge design policy with policies from other states is not conducted because the SAC agreed to restrict the comparison for culverts only.

### TASK 2: COST BENEFIT ANALYSIS

The cost benefit analysis is performed in the light of suggested revision in culvert hydraulics policy (Box 1). INDOT provided a total of sixteen culvert design examples including both new-alignment and replacement structures. These culvert designs are reviewed, and structures are redesigned (if needed) to have a maximum back water of 1’ as suggested in the revised INDOT policy. A comparison of old design with new design is made to quantify the changes in culvert size and outlet velocity.

To convert culvert size reduction into actual dollar amount, a regression model (Section 2.3) is developed based on bid prices of more than 500 culverts. The bid price data for this analysis is provided by INDOT. Bid prices used in this analysis represent “fully loaded” prices of per unit length of finished work including all materials, time, and labor. Because of the competition, bid prices may be influenced by other factors that go beyond the cost of actual labor and materials alone.

#### 2.1 Culvert Re-designing

Out of sixteen culvert designs reviewed, seven designs (referred as Group 1) used 0.14’ maximum backwater, but can have up to 1’ maximum backwater as per the suggested revision (see ‘Culv7-NewAlg’ sheet in Culvert_Ana_Rev2.xlsx). The remaining nine culvert designs (referred as Group 2) either used 1’ maximum backwater mostly because they were replacement structures, or 1’ backwater was implemented with special permission from INDOT (see ‘Culv9-Replace’ sheet in Culvert_Ana_Rev2.xlsx). Group 1 culverts were redesigned using HY-8 for maximum 1’ backwater limit. There were twelve culvert designs (sample size) in Group 1, because in most cases each culvert site has two (alternative) proposed structures. Several (range: 3–7) alternative structures were tried until backwater reached the maximum limit of 1.0’ (‘Culv7-NewAlg’ sheet in Culvert_Ana_Rev2.xlsx).

#### 2.2 Specific Example of New Alignment Structures

Five structures in Group 1 are 4-sided concrete box culverts. Bid prices corresponding to the same culvert size (in terms of area) are compared for the original proposed structure and the reduced structure size after implementing the 1’ backwater limit. There is a wide range of bid prices corresponding to same structure size (Fig.2.1 a – d). Factors affecting unit bid price include total length of finished work, competition among bidders, and site accessibility. Average saving as a result of reduction in structure size is presented in Table 2.2. One to one match (corresponding to same contact number) is not found in the provided data, and thus only general results are presented.

#### 2.3 Specific example of replacement/special permission structures

There are nine structures where 1’ backwater was used either because they were replacement structures or new structure with special permission of 1’ backwater. In some cases, existing backwater was excessively high. These structures include CN-51750-US50 Seg. 7 struc-
TABLE 2.1
Reduction in culvert structure size due to increase in backwater limit to 1’

<table>
<thead>
<tr>
<th>Final Backwater (feet)</th>
<th>Decrease in culvert area (%)</th>
<th>Increase in outlet velocity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.79</td>
<td>44</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.62</td>
<td>-21</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.98</td>
<td>-62</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.11</td>
<td>12</td>
</tr>
<tr>
<td>Sample Size</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

| Average saving in bid price due to increase in back water limit to 1’ |
|---|---|---|
| Minimum structure size for 0.14’ back water | 7’ x 3’ CB | $80 | 18% | 12% |
| Minimum structure size for 1.0’ back water | 4’ x 3’ CB | $392 | 58% | 31% |
| Average saving in the bid price per unit length (feet) of structure from data | $682 | 44% | 65% |
| % average saving from data | $181 | 31% | 16% |

2.4 General Linear Regression Model for cost-benefit analysis

INDOT provided the data for bid prices of culvert structures (3-sided and 4-sided structures) between year 2005 and 2010. Based on these data, a general linear regression model is developed for 3-sided and 4-sided structures, separately. Major steps involved in model development are briefly described below.

Step1: The data is cleaned up to have only 3-sided and 4-sided culvert structures. Accessories structures such as wing wall, head wall, retaining walls, tie-back wall, etc. were removed from the original data because these items were quoted separately from the culvert structures.

Step2: Necessary unit conversion is implemented to bring all data in a single unit format i.e. culvert area in ft x ft, and bid price in $ per unit length (foot) of the culvert structure.

Step3: Culvert sizes are represented in terms of their area, e.g. 6 ft x 4 ft culverts is represented by 24 ft² culvert area. No distinction is made when two structure sizes resulted in the same area e.g. 6 ft x 4 ft and 8 ft x 3 ft.

Step4: Three-sided and 4-sided structures are analyzed separately. Three-sided structures are in general higher sizes (average: 196 ft², range: 43 to 588 ft²), compared to 4-sided structures (average: 42 ft², range: 6 to 128 ft²).

Step5: Logarithmic transformation (log10) is implemented in per unit bid price to stabilize the variance in the data.

Step6: Given bid prices are for year 2005 to 2010. For four sided structures, separating the data set into different years (to account for inflation) were tried, but final results are presented by combining all the data sets to cover wide range of structure sizes and large number of sample sizes. In the case of 4 sided structures final sample size (after removing outliers) is 433 and for 3-sided structures sample size is 137.

Step7: Linear regression model is implemented in SAS, and outliers are removed based on cookd values. Ten outlier observations (cookd > 0.02) were removed

TABLE 2.2
Average saving in bid price due to increase in back water limit to 1’. Note: Model is described in Section 2.3

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Crossing Name</th>
<th>minimum structure size for 0.14’ back water</th>
<th>minimum structure size for 1.0’ back water</th>
<th>average saving in the bid price per unit length (feet) of structure from data</th>
<th>% average saving from data</th>
<th>% saving from model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SR-58W</td>
<td>7’ x 3’ CB</td>
<td>4’ x 3’ CB</td>
<td>$80</td>
<td>18%</td>
<td>12%</td>
</tr>
<tr>
<td>2</td>
<td>CN-224400, Seg-11</td>
<td>9’ x 5’ CB</td>
<td>5’ x 4’ CB</td>
<td>$392</td>
<td>58%</td>
<td>31%</td>
</tr>
<tr>
<td>3</td>
<td>CN-222800, Seg-11</td>
<td>18’ x 8’ CB</td>
<td>12’ x 6’ CB</td>
<td>$682</td>
<td>44%</td>
<td>65%</td>
</tr>
<tr>
<td>4</td>
<td>LSR 11, Seg - 4</td>
<td>9’ x 4’ CB</td>
<td>6’ x 4’ CB</td>
<td>$181</td>
<td>31%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Fig. 1 (d)
Fig. 2.1 Saving in culvert bid price due to increased in backwater limit to 1’
<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Crossing Name</th>
<th>Existing Structure</th>
<th>Existing backwater</th>
<th>Proposed Replacement Structure size</th>
<th>proposed backwater</th>
<th>average increase in the bid price per unit length (feet) of structure from data</th>
<th>% increase from data</th>
<th>increase in the bid price per unit length (feet) of structure from model</th>
<th>% increase from model</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>US 24 Newton County, Des. # 0200068</td>
<td>4’ × 3’ conc. Box</td>
<td>3.1’</td>
<td>9’ × 4’ CB</td>
<td>0.79’</td>
<td>$218</td>
<td>61%</td>
<td>$151</td>
<td>42.50%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CN-49600-US50, Seg-7</td>
<td>18’ × 3’ conc. Box</td>
<td>0.71</td>
<td>19’ × 4’ CB</td>
<td>0.68’</td>
<td>$136</td>
<td>19%</td>
<td>$252</td>
<td>38.30%</td>
<td>Note 1</td>
</tr>
<tr>
<td>3</td>
<td>CR1200N</td>
<td>1.25’ CMP</td>
<td>1.06’ (Note 3)</td>
<td>6’ × 4’ CB</td>
<td>1.01’</td>
<td>$121</td>
<td></td>
<td>$121</td>
<td>40%</td>
<td>Note 2</td>
</tr>
<tr>
<td>4</td>
<td>SR66 Spencer County Des# 0800794</td>
<td>10’ dia structural steel plate pipe</td>
<td>4.38’</td>
<td>12’ × 8’ CB</td>
<td>1.0’</td>
<td>$278</td>
<td></td>
<td>$278</td>
<td>29.50%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CN-51750-US50, Seg-7</td>
<td>3’ dia corrugated steel pipe</td>
<td>9.5’</td>
<td>9’ × 4’ CB</td>
<td>0.87’</td>
<td>$176</td>
<td></td>
<td>$176</td>
<td>53%</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: increase from data is calculated from 10*8 size structure because no 19*4 structure was available in the data
Note 2: no data correspond g to pipe structure is available. Hence for existing structure bid price is calculated from corresponding area 4 sided structures using the model
Note 3: In the case of existing structure (1.25 CMP) 95% of design discharge (116 cfs) was flowing as roadway discharge.
Fig. 2.2 Increase in culvert bid price due to replacement structure

TABLE 2.4
Parameter estimates of general linear regression model of four sided structures

<table>
<thead>
<tr>
<th>Variable</th>
<th>Label</th>
<th>DF</th>
<th>Parameter estimate</th>
<th>Standard error</th>
<th>t Value</th>
<th>Pr &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>Intercept</td>
<td>1</td>
<td>2.4732</td>
<td>0.01161</td>
<td>213.03</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>slope</td>
<td>slope</td>
<td>1</td>
<td>0.0064</td>
<td>0.00022</td>
<td>29.03</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>
from 4-sided structures and five outlier observations (cookd $> 0.04$) were removed from 3-sided structures.

2.3.1 Results: General Linear Regression Model for 4-sided structures

\[
\log_{10}(bdprUL) = m * (area) + c
\]

Where \(bdprUL\) is the bid price per unit length ($$/ft), \(m\) is slope, \(c\) is intercept, and \(area\) in ft\(^2\). Parameter estimates and statistical significance are given in Table 2.4. RSquare of model fit is: 0.66 (Fig. 2.3). Diagnostics of linear model is shown in Fig. 2.4.

2.3.2 Results: General Linear Regression Model for 3-sided structures

\[
\log_{10}(bdprUL) = m * (area) + c
\]

Where \(bdprUL\) is the bid price per unit length ($$/ft), \(m\) is slope, \(c\) is intercept, and \(area\) in ft\(^2\). Parameter estimates and statistical significance are given in Table 2.5. RSquare of model fit is: 0.40 (Fig. 2.5). Diagnostics of linear model is shown in Fig. 2.6.

2.3.3 Discussion

Parameter estimates are found statistically significant for both 4-sided and 3-sided structures. Better model fit (RSquare = 0.66) is found in 4-sided structures compared to 3-sided structures (RSquare = 0.40). Four sided structure model provided conservative estimate of saving in 3 out of 4 structures shown in Table 2.2. Further investigation is needed to account for yearly inflation rate, and total length of culvert in the bid price model.

| Variable | Label   | DF | Parameter Estimate | Standard Error | t Value | Pr > |t| |
|----------|---------|----|--------------------|----------------|---------|-------|
| Intercept | Intercept | 1  | 3.02623            | 0.02776        | 109.03  | <.0001 |
| slope    | slope   | 1  | 0.00124            | 0.00013        | 9.54    | <.0001 |

Fig. 2.3 General linear regression model for 4-sided structures.
Fig. 2.4 Model diagnostics for 4-sided structures.
Fig. 2.5  General linear regression model for 3-sided structures.
TASK 3: INVESTIGATE WAYS TO IMPROVE HYDRAULIC DESIGN

Investigation is carried out to determine sources of uncertainty on design flow calculations. Here uncertainty analysis for a specific example of culvert design is presented.

Culvert design for crossing CR 1200 N located in Section 34, Township 5 North, Range 6 West, Bogard Township in Epsom Quadrangle, Daviess County, Indiana, is reviewed for uncertainty estimate in the design calculations.

Proposed structure is a small culvert, hence preferred method of $Q_{100}$ calculation is: (1) T20, and (2) Rational Method. (Fig. 29-6A, INDOT design manual)

Note 1: Design $Q_{100}$ in the given report (provided by INDOT) was based on Rational Method. Differences in the rational method design estimate in the report (116.86 cfs) and the value presented here (138.3 cfs) can be due to differences in precipitation frequency estimates. Precipitation frequency estimate is based on 38.82970 latitude, and -87.03722 longitudes.

Note 2: TR20 calculation is based on composite CN = 76.5 (Hydrologic Soil Group: B; 93% Row Crop), and Huff distribution of design rainfall (Indianapolis area) for 1 hour storm.

Major Findings are:

1. Highest uncertainty (~ 2 fold increase in design discharge) comes from change in AMC from II to III.
2. HY-8 design performed in the study show that the proposed structures (6’x4’ Precast Concrete Box, and 9’x4.71’ Open Bottom Corrugated Metal Arch) fail to meet the design requirement of 1’ maximum backwater for discharge higher than 116.86 cfs. For example, for
158.83 cfs peak flow, backwater is 1.92’ in 6’ × 4’ Precast Concrete Box.

Based on this analysis following recommendations are made to improve design discharge calculation:

1. Please mention latitude and longitude of the site location.
2. Design discharge calculation based on at least two methods of calculation (Preference 1 and 2, as given in Fig. 29-6A, INDOT design manual) should be presented in the report. In the case of small culverts, two preferred methods are T20 and Rational method.
3. Known sources of uncertainty (e.g. change in AMC, CN, precipitation frequency estimate) should be incorporated in Q100 calculation.
4. Design based on AMC III may be considered because high floods are more likely to occur in wet years compared to dry years. However, this issue should be discussed and decided by the SAC committee.
5. Guidelines should be made to incorporate Q100 uncertainty estimate in the culvert design (e.g. relaxation in 1’ maximum backwater limit if AMCIII design discharge is used)
6. Please provide shape file (GIS data) for the delineated watershed for the culvert. It will be helpful in extracting the available digital data (e.g. soil hydrologic group, land cover, CN) for the study area. StreamStat can be used to delineate the watershed.

REFERENCES